The primary features of a first embodiment of the invention of a method of predicting biomacromolecule crystallization conditions and for crystallizing biomacromolecules are provided hereinafter with reference to FIG. 1A in FIGs. 2–6. The primary features of a second embodiment of the invention are provided hereinafter with reference to FIG. 1B in FIGs. 2–5 and FIGs. 7–15. In the first embodiment, a crystal equilibrium condition in FIG. 1A is expressed by means of a macromolecule solubility curve serving as a boundary separating two regions of experimental parameter values: a region where crystallization can occur, and a region where crystallization cannot occur.

The method described in the first embodiment establishes a biomacromolecule equilibrium concentration in the context of the applied experimental conditions. The biomacromolecule concentration to be used for crystallization must exceed the obtained equilibrium value. In a second embodiment, an aggregation boundary condition in FIG. 1B is expressed by means of a window of experimental parameter values above which the amorphous aggregation is likely to occur. The terms "aggregation" and "amorphous aggregation" are used interchangeably.

Theoretical Introduction

In attempts to crystallize biomacromolecules from a solution, it is desirable to obtain as much as possible single crystals with as few defects as possible, and to avoid amorphous aggregations of molecules, since amorphous aggregates are not crystals. The present invention takes advantage of the property of biomacromolecules to have mixed hydrophobic and hydrophilic regions. This property results in a tendency for these molecules to assembly either in the bulk or at the surface of the solution. In this disclosure, the surface of the solution can be adjacent to another material or to empty space, and hence the surface can be in contact with a solid or with a liquid or with a gas, that is usually air. The surface of the solution has a surface tension and a surface pressure, which terms in this case include an interfacial tension or an interfacial pressure.

It is possible to define one or more assembly parameters that reach a critical response as increasingly more molecules participate in assembly formation. For example, the tendency of biomacromolecules to assembly in a solution can be monitored by taking surface tension or surface pressure measurements of the solution.

1. A method for predicting a crystal equilibrium condition for biomacromolecule crystallization and for crystallizing a biomacromolecule, comprising

setting up at least one biomacromolecule solubility experiment comprising the steps of

a) preparing a solution of the biomacromolecule in a solvent, the solution having a biomacromolecule concentration,

b) selecting a variable quantity,

c) selecting an assembly parameter being one or more of a surface tension and a surface pressure,

d) monitoring a response of the assembly parameter while varying the variable quantity in a suitable way so that the response exhibits a transition,

e) obtaining an equilibrium biomacromolecule concentration based on the transition,

f) defining a crystal equilibrium condition according to which a biomacromolecule crystallization concentration exceeds the equilibrium biomacromolecule concentration,

and crystallizing the biomacromolecule.

2. The method as claimed in Claim 1, wherein the solution has further a pH and a temperature, and the variable quantity is one of the biomacromolecule concentration, the pH and the temperature.

3. The method as claimed in Claim 2, wherein the solution further comprises an additive, the solution has an additive concentration, and the variable quantity is one of the biomacromolecule concentration, the pH, the temperature and the additive concentration.

4. The method as claimed in Claim 1, wherein the solution has a surface.

5. The method as claimed in Claim 4, wherein the biomacromolecule is not prone to unfolding at the surface of the solution.

6. The method as claimed in Claim 2 or Claim 3, wherein the transition is associated with a critical magnitude of the variable quantity.

7. The method as claimed in Claim 2 or Claim 3, wherein the transition is between a changing response of the assembly parameter and a substantially unchanging response of the assembly parameter.

8. The method as claimed in Claim 2 or Claim 3, wherein the transition is associated with a critical magnitude of the variable quantity, and further wherein the transition is between a changing response of the assembly parameter and a substantially unchanging response of the assembly parameter.

9. The method as claimed in Claim 8, wherein the substantially unchanging response corresponds to a substantially minimal value of the assembly parameter.

10. The method as claimed in Claim 8, further defining the crystal equilibrium condition in terms of the critical magnitude, wherein the crystal equilibrium condition prescribes that no crystallization occurs when the variable quantity is smaller than the critical magnitude.

11. The method as claimed in Claim 10 wherein the variable quantity is the biomacromolecule concentration, and consequently the equilibrium biomacromolecule concentration equals the critical magnitude.

12. The method as claimed in Claim 10 wherein the variable quantity is not the biomacromolecule concentration, and consequently the equilibrium biomacromolecule concentration equals the biomacromolecule concentration.

13. The method as claimed in Claim 1, wherein the biomacromolecule to be crystallized is a protein.

14. The method as claimed in Claim 13, wherein the protein has a weight less than 200 kDalton.

15. The method as claimed in Claim 14, wherein the protein is one of a lysozyme and a concanavalin A.

16. The method as claimed in Claim 1, wherein the biomacromolecule to be crystallized is a polypeptide.

17. The method as claimed in Claim 1, wherein the biomacromolecule to be crystallized is a nucleic acid.

18. The method as claimed in Claim 1, wherein the biomacromolecule to be crystallized is a virus.

19. The method as claimed in Claim 1, wherein the biomacromolecule to be crystallized is a virus fragment.

20. The method as claimed in Claim 3, wherein the additive is a salt.

21. The method as claimed in Claim 3, wherein the additive comprises organic molecules.

22. The method as claimed in Claim 3, wherein the additive comprises polymers.

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23. A method for predicting a crystal equilibrium condition for protein crystallization and for crystallizing a protein, comprising

setting up at least one biomacromolecule solubility experiment, comprising the steps of

a) preparing a solution of the protein in a solvent, the solution further comprising an additive, the solution having a protein concentration, an additive concentration, a pH and a temperature, the solution having a surface, the surface having a surface tension and a surface pressure, the protein being not prone to unfolding at the surface,

b) defining an assembly parameter to be one of the surface tension and the surface pressure,

c) selecting a first variable quantity and a second variable quantity from the protein concentration, the additive concentration, the pH and the temperature,

d) varying the first variable quantity in a suitable way so that the assembly parameter exhibits a transition between a changing response and a substantially unchanging response, wherein the substantially unchanging response corresponds to a first substantially minimal value of the assembly parameter, the transition being associated with a first critical magnitude of the first variable quantity,

e) varying the second variable quantity in a suitable way so that the assembly parameter exhibits a transition between a changing response and a substantially unchanging response, wherein the substantially unchanging response corresponds to a second substantially minimal value of the assembly parameter, the transition being associated with a second critical magnitude of the second variable quantity,

f) constructing a solubility curve comprising points, each point being a pair of the first critical magnitude and the second critical magnitude, in order to assist in defining a crystal equilibrium condition,

g) obtaining an equilibrium protein concentration and defining the crystal equilibrium condition which is based on the solubility curve, and which prescribes that crystallization occurs when the first variable quantity exceeds the first critical magnitude of the pair, and the second variable quantity exceeds the second critical magnitude of the pair,

and crystallizing the protein using a protein crystallization concentration exceeding the equilibrium protein concentration.

24. The method as claimed in Claim 23, where in step (c) the protein concentration is one of the first variable quantity and the second variable quantity, and hence in step (g) the

equilibrium protein concentration is correspondingly one of the first critical magnitude and the second critical magnitude.

25. The method as claimed in Claim 23, where in step (c) the protein concentration is not one of the first variable quantity and the second variable quantity, and hence in step (g) the equilibrium protein concentration is the protein concentration.

26. The method as claimed in Claim 23, wherein the protein is one of the lysozyme and the concanavalin A and the additive is a salt.

27. A method for predicting an aggregation boundary condition for biomacromolecule crystallization and for crystallizing a biomacromolecule, comprising

setting up at least one aggregation boundary condition experiment comprising

a) preparing a solution of the biomacromolecule,

b) selecting a variable quantity,

c) selecting an assembly parameter being one or more of a surface tension and a surface pressure,

d) measuring the assembly parameter at different times,

e) registering an equilibrium assembly parameter

f) deriving a crystallization coefficient from the equilibrium assembly parameter, the crystallization coefficient being associated with the variable quantity,

g) using an aggregation indicator to define an aggregation boundary condition for the biomacromolecule, the aggregation boundary condition prescribing that an aggregation occurs when the crystallization coefficient associated with the variable quantity is larger than the aggregation indicator,

and crystallizing the biomacromolecule.

28. A method for predicting an aggregation boundary condition for biomacromolecule crystallization and for crystallizing a biomacromolecule, comprising

setting up at least one aggregation boundary condition experiment comprising

a) preparing a solution of the biomacromolecule in a solvent, the solution having a biomacromolecule concentration and a surface, the surface having a surface pressure,

b) selecting a variable quantity,

c) obtaining the surface pressure at different times, while varying the variable quantity,

d) recording a time dependent equilibrium surface pressure which is associated with the variable quantity,

e) formulating a time-dependence profile based on the equilibrium surface pressure, which is associated with the variable quantity,

f) deriving from the time-dependence profile a crystallization coefficient of the biomacromolecule, that is associated with the variable quantity,

g) obtaining from the crystallization coefficient an aggregation indicator in order to define an aggregation boundary condition for the biomacromolecule, the aggregation boundary condition prescribing that an aggregation occurs when the crystallization coefficient associated with the variable quantity is larger than the aggregation indicator, and crystallizing the biomacromolecule.

29. The method as claimed in Claim 28, wherein the biomacromolecule is not prone to unfolding at the surface of the solution.

30. The method as claimed in Claim 28, wherein the solution further has pH and a temperature.

31. The method as claimed in Claim 28, wherein the biomacromolecule concentration is in the range 0.01 – 1.2 mg/ml.

32. The method as claimed in Claim 28, wherein the solution further comprises an additive and the solution has an additive concentration.

33. The method as claimed in Claim 30, wherein the variable quantity is one of the biomacromolecule concentration, the pH and the temperature.

34. The method as claimed in Claim 32, wherein the variable quantity is one of the biomacromolecule concentration, the additive concentration, the pH and the temperature.

35. The method as claimed in Claim 28, wherein the step of deriving the crystallization coefficient comprises the steps of

obtaining a diffusion time of the biomacromolecule,

obtaining an integration time of the biomacromolecule,

dividing the integation time by the diffusion time to obtain the crystallization coefficient of the biomacromolecule, that is associated with the variable quantity.

36. The method as claimed in Claim 28 wherein the time-dependence profile is given by $\ln(1-p/p_{eq})$, where ln is the natural logarithm, p is the surface pressure and p_{eq} is an equilibrium surface pressure.

37. The method as claimed in Claim 36, where the step of deriving the crystallization coefficient comprises the steps of

constructing a plot of the time-dependence profile against a time,

identifying on the plot of the time-dependence profile a first substantially straight linear segment, a second substantially straight linear segment and a third substantially straight linear segment, where the second substantially straight linear segment is later in the time than the first substantially straight linear segment and the second substantially straight linear segment is later in the time than the third substantially straight linear segment,

equating a diffusion time to an inverse slope of the first substantially straight linear segment,

equating a penetration time to an inverse slope of the second substantially straight linear segment,

equating a rearrangement time to an inverse slope of the third substantially straight linear segment,

adding the penetration time and the rearrangement time to obtain an integration time

dividing the integration time by the diffusion time to obtain the crystallization coefficient of the biomacromolecule, that is associated with the variable quantity.

38. The method as claimed in Claim 28, wherein the biomacromolecule to be crystallized is a protein.

39. The method as claimed in Claim 38, wherein the protein has a weight less than 200 kDalton.

40. The method as claimed in Claim 39, wherein the protein is one of a lysozyme and a concanavalin A.

41. The method as claimed in Claim 28, wherein the biomacromolecule to be crystallized is a polypeptide.

42. The method as claimed in Claim 28, wherein the biomacromolecule to be crystallized is a nucleic acid.

43. The method as claimed in Claim 28, wherein the biomacromolecule to be crystallized is a virus.

44. The method as claimed in Claim 28, wherein the biomacromolecule to be crystallized is a virus fragment.

45. The method as claimed in Claim 32, wherein the additive is a salt.

46. The method as claimed in Claim 32, wherein the additive comprises organic molecules.

47. The method as claimed in Claim 32, wherein the additive comprises polymers.

48. The method as claimed in Claim 28, wherein the aggregation indicator is below 9.

49. The method as claimed in Claim 28, wherein the aggregation indicator is below 8.5.

50. The method as claimed in Claim 28, wherein the aggregation indicator is in a range from 4 to 9.

51. The method as claimed in Claim 28, wherein the aggregation indicator is in a range from 4.5 to 8.5.

52. A method for predicting an aggregation boundary condition for protein crystallization and for crystallizing a protein, comprising

setting up at least one aggregation boundary condition experiment comprising

a) preparing a solution of the protein in a solvent, a salt, and a suitable buffer, the solution having a salt concentration, a protein concentration in a range 0.01—1.2 mg/ml, a pH and a temperature, the solution having a surface, the surface having a surface pressure, the protein not being prone to unfolding at the surface of the solution,

b) obtaining the surface pressure at different times, while varying the salt concentration,

c) recording a time-dependent equilibrium surface pressure, which corresponds with an equilibrium time, and which is associated with the salt concentration,

d) formulating a time-dependence profile, which is given by $\ln(1-p/p_{eq})$, where ln is the natural logarithm, p is the surface pressure and p_{eq} is an equilibrium surface pressure, and which is associated with the salt concentration,

e) constructing a plot of the time-dependence profile against a time,

f) identifying on the plot a first substantially straight linear segment, a second substantially straight linear segment and a third substantially straight linear segment, where the second substantially straight linear segment is later in the time than the first substantially straight linear segment, and the third substantially straight linear segment is later in time than the second substantially straight linear segment,

g) equating a diffusion time to an inverse slope of the first substantially straight linear segment,

h) equating a penetration time to an inverse slope of the second substantially straight linear segment,

i) equating a rearrangement time to an inverse slope of the third substantially straight linear segment,

j) adding the penetration time and the rearrangement time to obtain an integration time

k) dividing the integration time by the diffusion time to obtain the crystallization coefficient of the protein, that is associated with the salt concentration,

g) obtaining from the crystallization coefficient an aggregation indicator in order to define an aggregation boundary condition for the protein, the aggregation boundary condition prescribing that an aggregation occurs when the crystallization coefficient associated with the salt concentration is larger than the aggregation indicator, the aggregation indicator being in a range from 4.5 to 8.5.

53. The method as claimed in Claim 52, wherein the protein is one of a lysozyme and a concanavalin A.

54. The biomacromolecule crystallized according to any one of the Claims 1—22 and 28—51.

55. The protein crystallized according to any one of the Claims 23—26, 52 and 53.